eRHIC Interaction Region Design

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Machine Advisory Committee, June 13-14, 2005

Three IR designs

- Two for ring-ring option, $l^* = 1.0\,\mathrm{m}$ (ZDR) and $l^* = 3.0\,\mathrm{m}$ (new design, preferred due to higher detector acceptance)

- Linac-ring option, $l^* = 5.0\,\mathrm{m}$

IR design goals

- Beam separation

- Accomodation of synchrotron radiation generated by beam separation

- Beam focusing to small spot sizes to maximize luminosity

Beam separation by a crossing angle

First hadron quadrupole (septum quad) starts approximately 5m from the IP

Required beam separation at septum:
$12\sigma_p + 20\sigma_e + d_{\text{septum}} \approx 25\,\text{mm}$

$\Rightarrow$ Required crossing angle to provide separation without additional dipoles:

$$\Theta \approx 5\,\text{mrad}$$

Large crossing angle reduces luminosity by factor ≈ 5 due to long hadron bunches

Crab Crossing

Required transverse deflecting voltage:

$$V_\perp = \frac{cE \tan \Theta}{e\omega_{\text{RF}}\sqrt{\beta^* \beta_{\text{crab}}}}$$

250 GeV protons (or 100 GeV/nucleon gold ions)
$\Theta = 5\,\text{mrad}$
$\beta_{\text{crab}} = 400\,\text{m}$, $\beta^* = 1\,\text{m}$
$\omega_{\text{RF}} = 2\pi \cdot 200\,\text{MHz}$

$$V_\perp = 15\,\text{MV}$$

For comparison: RHIC RF voltage is 2 MV, KEKB crab cavity voltage is 1.44 MV

Beam separation with zero crossing angle

Horizontal beam sizes at septum need to be kept small to minimize required beam separation

- hadrons:
  horizontal beam size at septum $\sigma_{x,h} \propto 1/\sqrt{\beta^*_{x,h}}$
  $\longrightarrow$ lower limit on $\beta^*_{x,h}$
  $\longrightarrow$ upper limit on luminosity

- electrons:
  horizontal beam size at septum $\sigma_{x,e} \propto \sqrt{\epsilon_{x,e}}$,
  but smaller $\epsilon_{x,e}$ requires larger $\beta^*_{x,e}$ to match beam sizes
  $\longrightarrow$ larger beam-beam parameter
  $\longrightarrow$ luminosity limitation for ring-ring design

Consequences for IR design

Ring-ring:

- elliptical cross section at the IP ($\sigma_x = 2 \cdot \sigma_y$)
  $\longrightarrow$ upright (hadron) beam ellipse at the septum
- minimize horizontal electron beam size at septum by proper focusing

Consequences for IR design

Linac-ring:

- Electron beam size at septum is “negligible” due to small ϵ, large β^*
  $\longrightarrow$ available separation at septum can be spend for hadron beam
  $\longrightarrow$ round beam cross section at IP

Synchrotron radiation issues

Beam separation close to the IP to bring proton low-β quads as close as possible to the IP

$\longrightarrow$ Generation of synchrotron radiation close to the IP, inside the detector volume

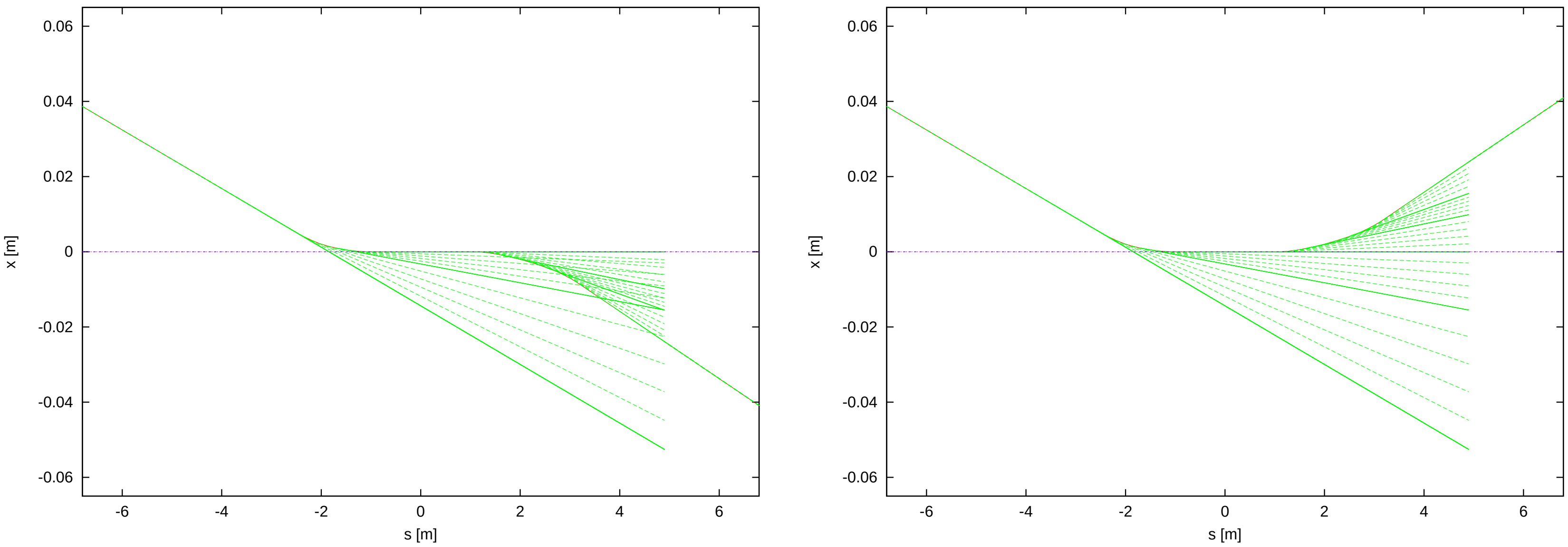
$\longrightarrow$ SR must be passed safely through the IP and the low-β electron quads

$\longrightarrow$ SR fan must be kept narrow to limit required quad aperture

$\longrightarrow$ separation as close as possible to the IP

$\longrightarrow$ S-shape IR preferred over C-shape

S-shape IR preferred over C-shape:



Low-β focusing

Low-β focusing is limited by hourglass effect:

$$\beta > \sigma_{p,s}$$

Hadron bunchlength $\sigma_{p,s}$ is limited by cryo load and IBS:

$$\sigma_{p,s} \approx 20\,\text{cm}$$

Hadron transverse emittance is given by present RHIC

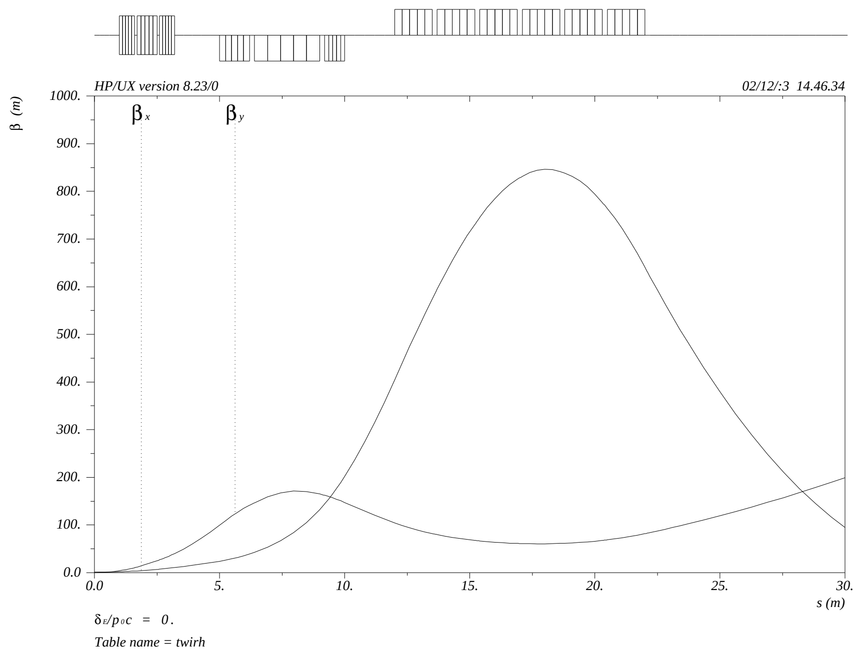
Keep beams at IP as round as possible to maximize luminosity and minimize beam-beam, but be aware of horizontal beam size at the septum

IR parameters for 10 GeV e on 250 GeV p

	ring-ring		linac-ring
	$l^* = 1\,\text{m}$	$l^* = 3\,\text{m}$	$l^* \geq 5\,\text{m}$
ϵ_h [nm]	9.5		9.5
ϵ_e (x/y) [nm]	53/9.5		2.5/2.5
β_h (x/y) [m]	1.08/0.27	2.16/0.54	0.27/0.27
β_e (x/y) [m]	0.19/0.27	0.38/0.54	0.99/0.99
σ^* (x/y) [μm]	100/50	140/70	50/50
N_e/bunch [10^{11}]	1.0	1.0	1.4
N_p/bunch [10^{11}]	1.0	1.0	1.0...2.0
ξ_h (x/y)	0.007/0.0035		0.007/0.007
ξ_e (x/y)	0.022/0.08		N/A
$\mathcal{L}$ [$10^{33}\,\text{cm}^{-2}\text{sec}^{-1}$]	0.44	0.22	1.25...2.5

Ring-ring IR lattice, $l^* = 1\,\text{m}$

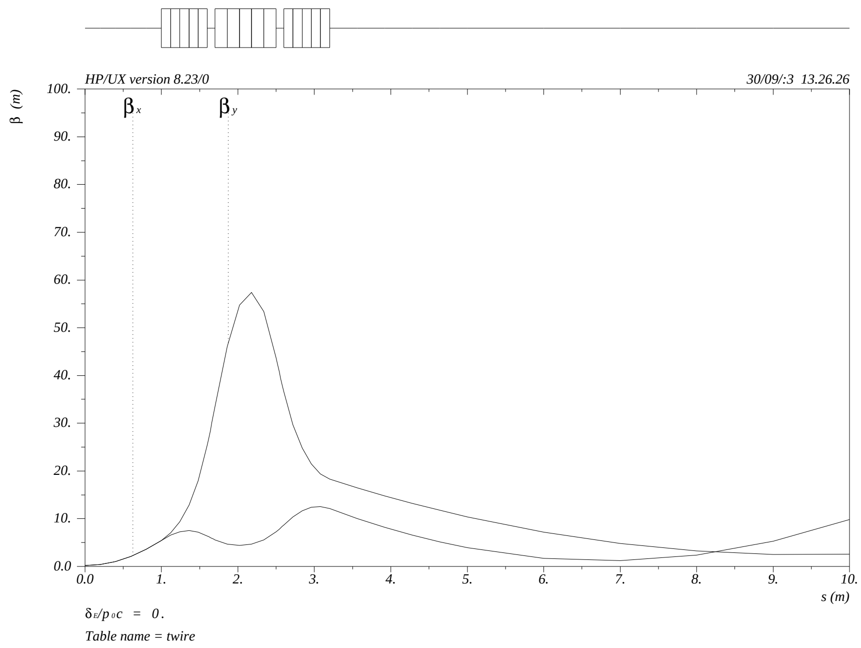
Hadron doublet:



Normal-conducting septum quads, 1.0 Tesla pole tip field

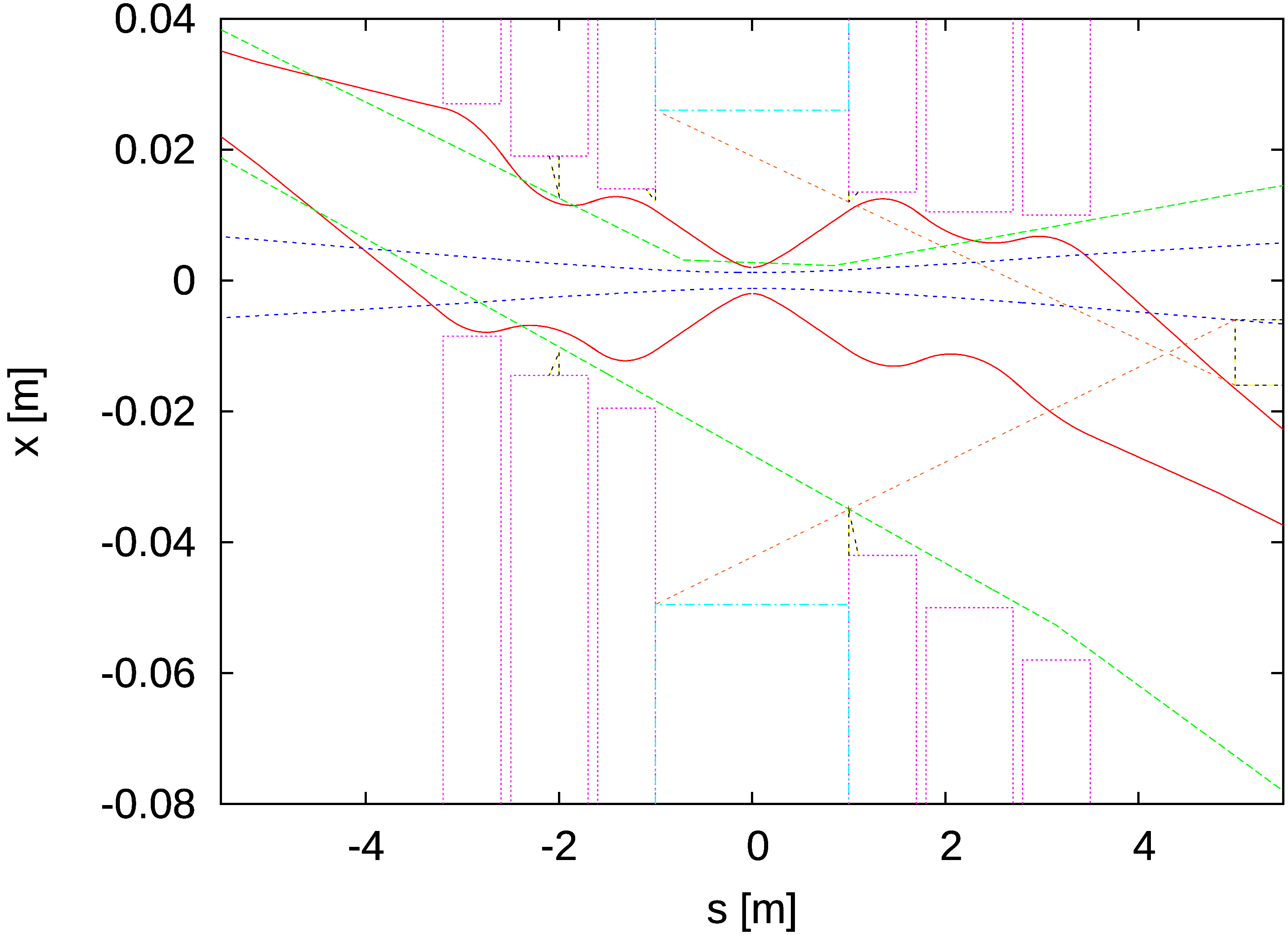
Ring-ring IR lattice, $l^* = 1\,\mathrm{m}$

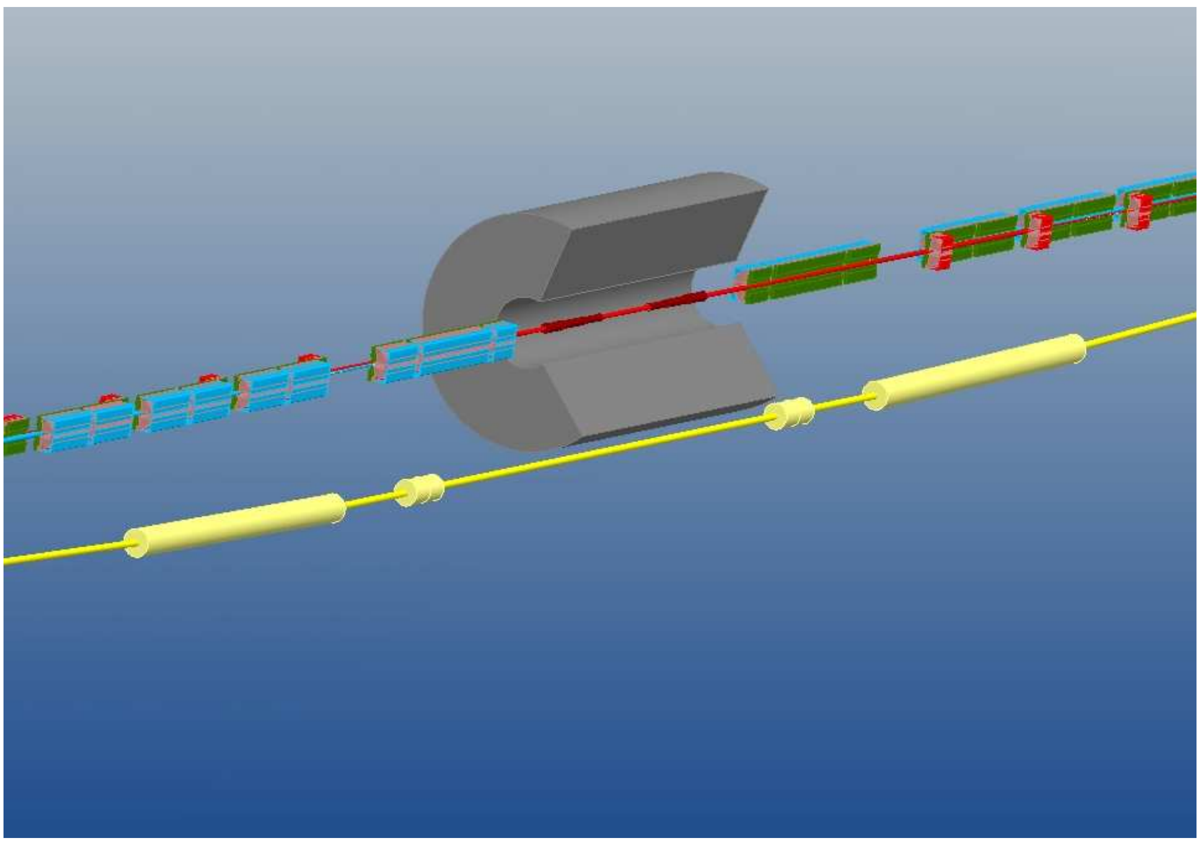
Electron triplet with dipole windings, inside detector:

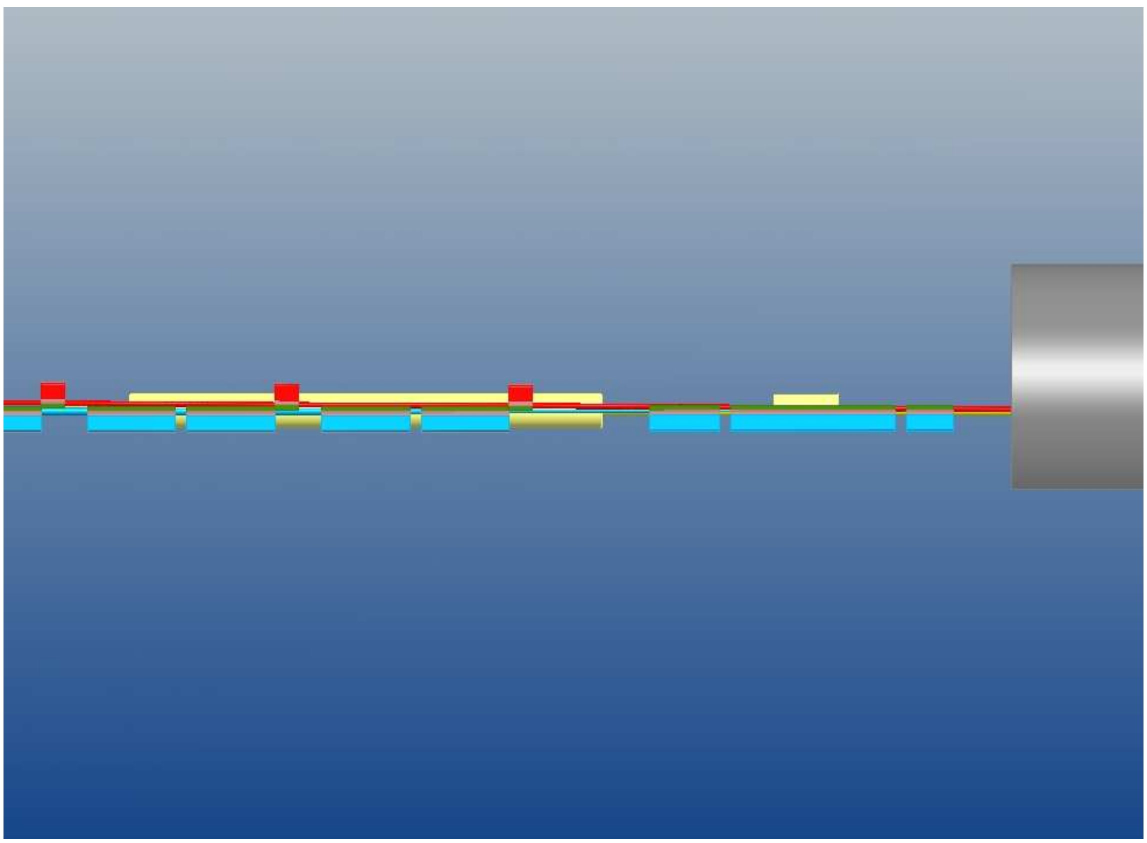


Superconducting quads, $\approx 2\,$Tesla peak field

Ring-ring IR, $l^* = 1\,\text{m}$

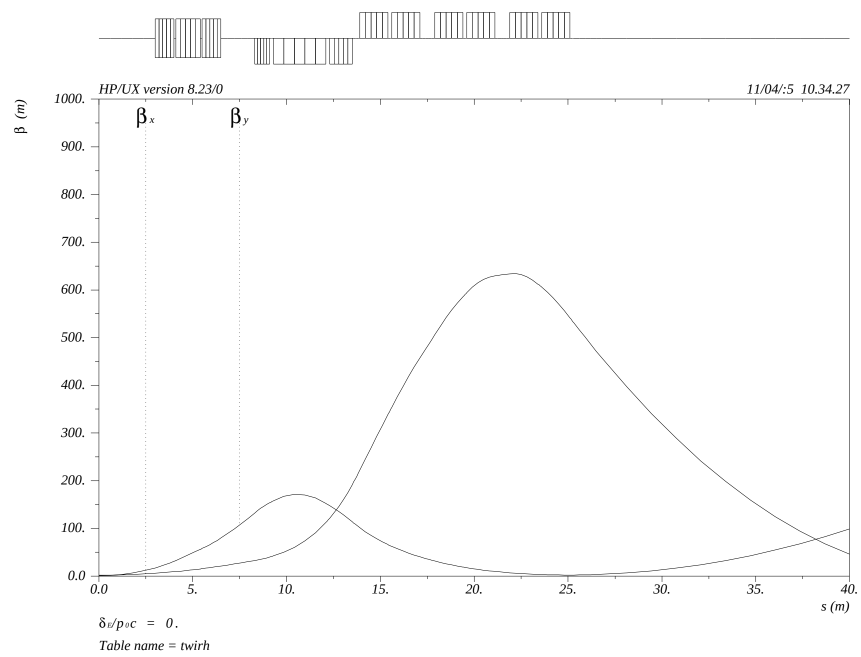






Ring-ring IR lattice, $l^* = 3\,\text{m}$

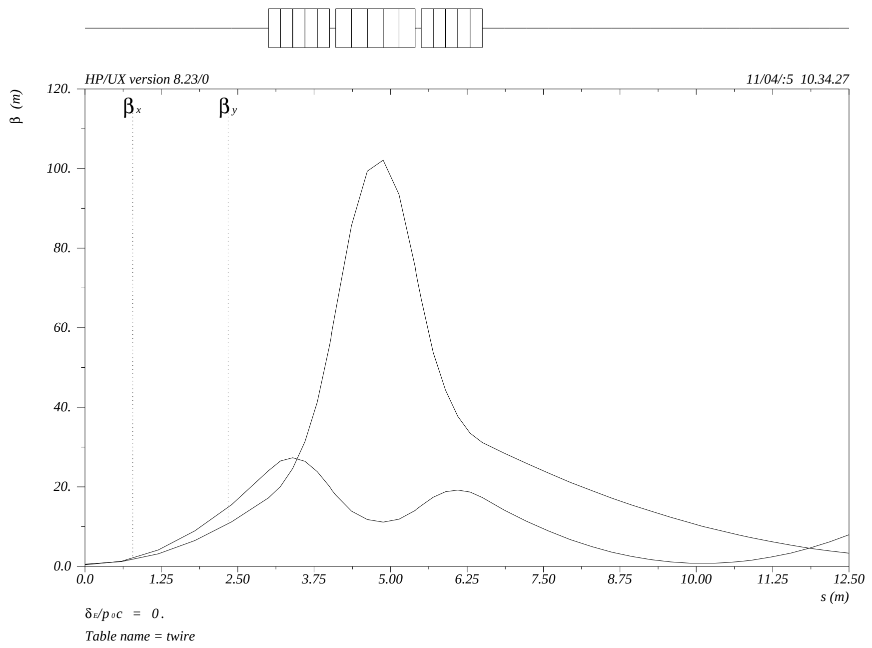
Hadron doublet:



Normal-conducting septum quads, 1.0 Tesla pole tip field

Ring-ring IR lattice, $l^* = 3\,\mathrm{m}$

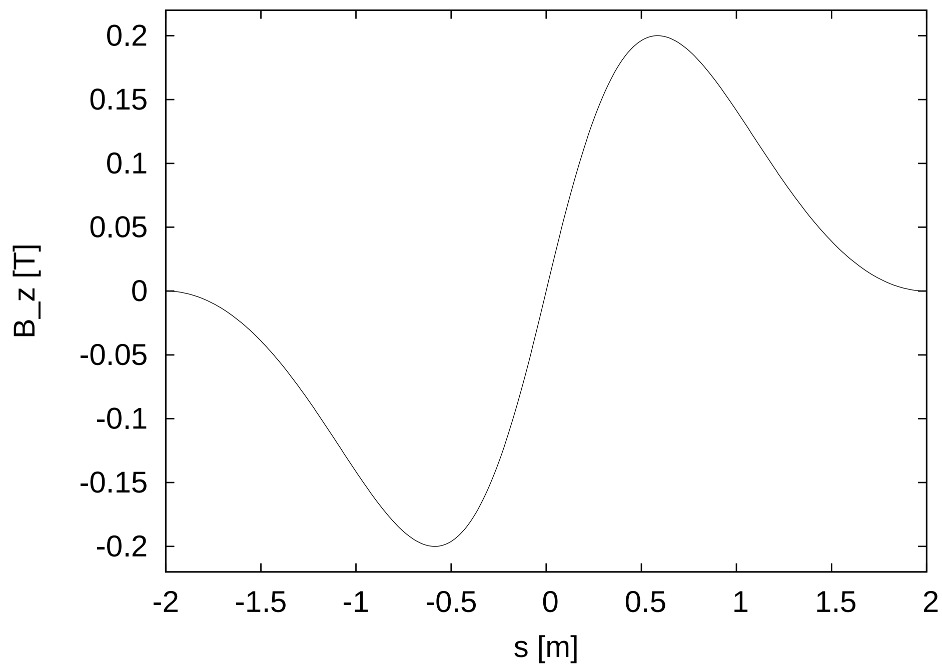
Electron triplet outside detector:



Superconducting quads, $\approx 2\,$Tesla peak field

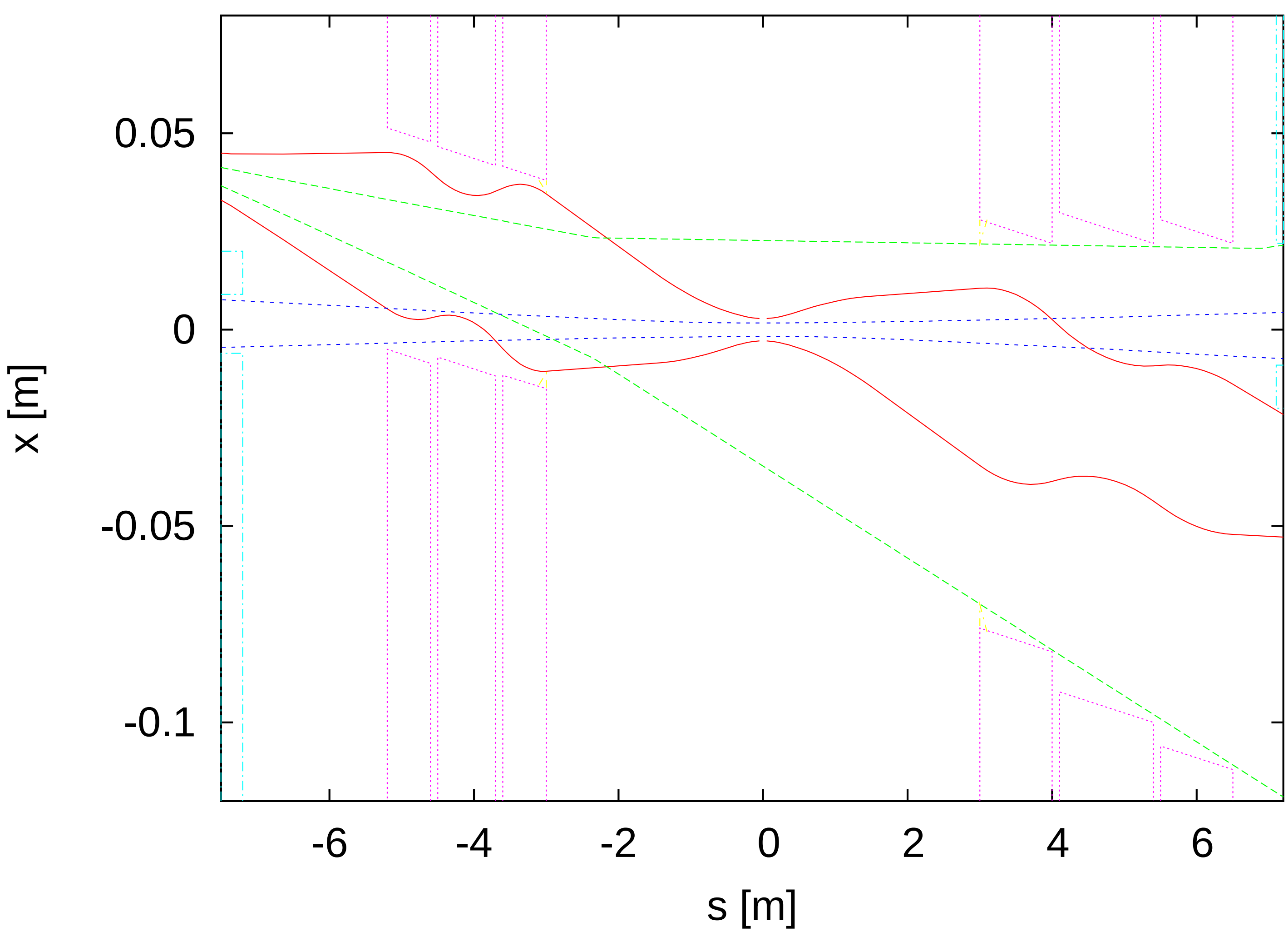
Ring-ring IR lattice, $l^* = 3\,\mathrm{m}$

Separator dipole field superimposed on detector solenoid (Detector Integrated Dipole, DID)



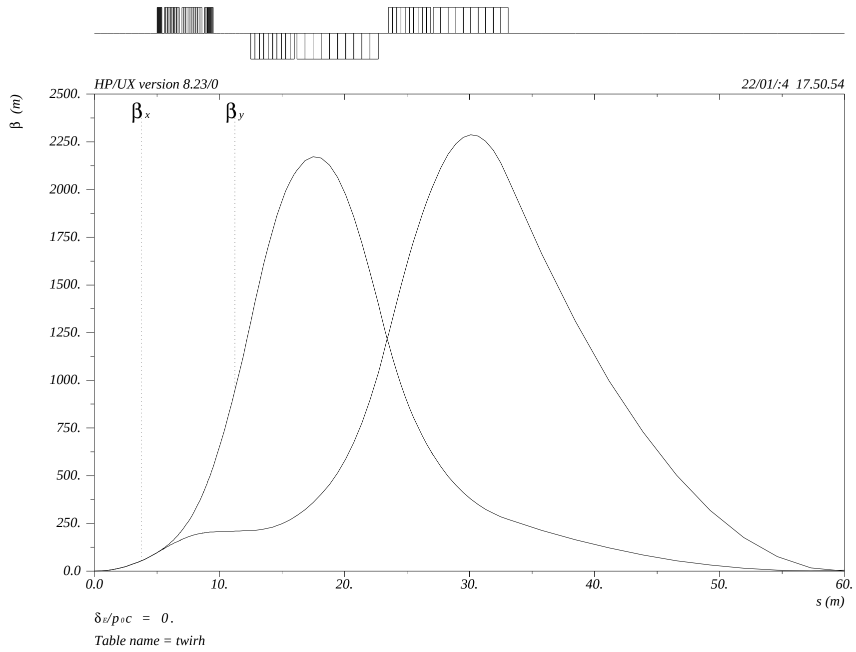
0.2 Tm integrated field for 6 mrad separation angle

Ring-ring IR, $l^* = 3\,\mathrm{m}$



Linac-ring IR lattice

Hadron triplet:



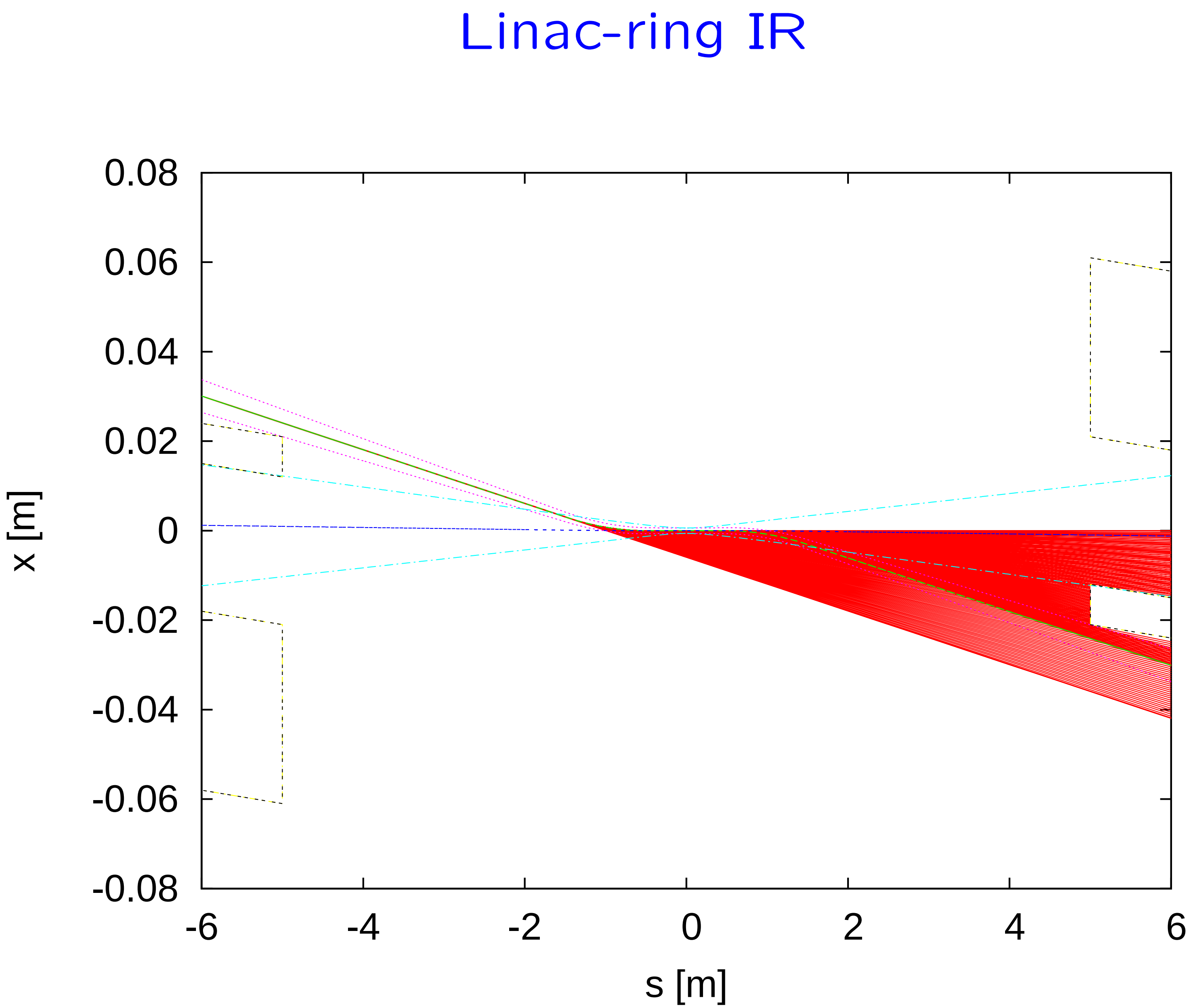
Normal-conducting septum quads, 1.0 Tesla pole tip field

Linac-ring IR lattice

Electrons:

- Focusing elements (normal-conducting) can be far away from the IP ($\geq$ 10 m) due to tiny emittance and relatively large β^*

- Separation by Detector Integrated Dipole (DID)



Linac-ring IR
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
x [m]
-6
-4
-2
0
2
4
6
s [m]

Conclusion

- Design considerations and limitations for eRHIC electron-ion IR have been presented.

- IR design solutions for both ring-ring and linac-ring option of eRHIC exist.

- Linac-ring option provides significantly higher luminosity for 10 GeV e on 250 GeV p.

- SR background simulations being worked on.